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FEASIBILITY STUDY FOR THE APPLICATION OF GAS EOR PROCESSES IN DOE'S NPR-3 RESERVOIRS

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FEASIBILITY STUDY FOR THE APPLICATION OF GAS EOR PROCESSES IN DOE'S NPR-3 RESERVOIRS

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EXECUTIVE SUMMARY

A preliminary screening study for the application of gas EOR technology to DOE's NPR-3 reservoirs concluded that gas, miscible CO_2, EOR technology is not applicable to NPR-3 reservoirs because the reservoir temperatures and pressures are too low and reservoir formation is fractured. Immiscible CO_2 flooding may, however, have application.

INTRODUCTION

Oil production from Teapot Dome (NPR-3) reservoirs (WY) is approaching economic limits of waterflooding, and applications of EOR technology should be considered. Among all EOR methods, steamflooding and chemical flooding have been considered, and laboratory studies are being made under separate projects (BE4A and BE11A). Although gas flooding has not been considered, it is of interest to investigate the applicability of gas injection to improve oil production. Some gas injection projects are being conducted in the Wyoming area. For example, Amoco Production Co. has conducted a CO_2 miscible displacement project in Lost Soldier oil field, and Kerr-McGee Oil Co. has conducted hydrocarbon miscible flooding in North Buck Draw field.[1]

The objective of this task is to conduct a preliminary study to investigate the feasibility of gas miscible or immiscible displacement for NPR-3 reservoirs. This study is a preliminary screening based on the phase behavior of the crude oil and reservoir conditions. Laboratory coreflooding experiments and full-scale reservoir simulations were not planned at this stage.

A brief summary of reservoir data for NPR-3 reservoirs is given in Table 1. In general, the crudes (30° to 40° API gravity) are good candidates for gas miscible displacement. Unfortunately, in the two major producing formations—2nd Wall Creek and Shannon—reservoir pressures have been depleted to a low level. Present reservoir temperatures and pressures for other formations are not available. Although detailed geological information is available and is being used for reservoir characterization studies, production data are scarce, and available production data are not complete. Reservoir fluid analysis data for a crude oil sample obtained from a well penetrating Shannon formation were provided by NPR-3 operator (Appendix). These data include reservoir condition, compositional analysis of recombined oil, saturation pressures, pressure-volume relations

TABLE 1
NPR-3 Reservoir Data

Formation	2nd Wall Creek	Shannon	Lakota	Morrison	Tensleep
Lithology	Sandstone	Sandstone	Sandstone	Sandstone	Sandstone
Porosity, %	16	16	15	16	11
Permeability, mD	10-50	50	5.5	Unknown	5
Average pay thick., ft	25	30	13	26	25
Depth, ft	2,210	Variable	Unknown	Unknown	Unknown
Initial pressure, psi	1,000	Unknown	1,850	1,430	2,333
Present pressure, psi	400-700	41-320	Unknown	Unknown	Unknown
Reservoir temp., °F	Unknown	60-70	Unknown	Unknown	Unknown
API gravity of oil, °F	36	35.2	46.9	35.5	29.6
Gas/oil ratio, scf/bbl	Variable	19.6	6,300	24	0
Drive mechanism	Solution gas	Solution gas	Solution gas & water drive	Water drive	Water drive

of reservoir fluid, and compositional analysis of separator products. These data, although not up-to-date (crude oil analysis was conducted in 1987) provided the information used for this study.

RESULTS AND DISCUSSION

Phase Behavior of Shannon Crude Oil

Based on compositional analysis, crude oil with more than 94 mol % of C_6+ is close to dead oil. The primary separator gas/oil ratio is only 19.1 scf/bbl at 60° F. Therefore, the saturation pressure is pretty low, as shown in Fig. 1. Under present reservoir conditions, (60° F, 50 psig), the crude is two-phase. The recombined crude oil composition was analyzed up to C_{11}+. The 15 components were lumped into 7 pseudocomponents, and the pressure-volume behavior of the crude oil at 65° F was reasonably matched with a 7-pseudocomponent system, as shown in Fig. 2. A ternary phase diagram is plotted in Fig. 3, which shows the two-phase region almost covers the entire phase region. It also shows that CO_2 is unable to achieve miscibility with the crude oil under reservoir conditions.

Preliminary Screening

According to the provided data for Shannon oil field, the reservoir temperature and pressure are low (T= 60° F, P=50 psig). Usually, lower temperature will lower minimum miscibility pressure (MMP), and thus favor gas miscible displacement; however, low temperature is always accompanied with low pressure, which does not favor gas miscible displacement.

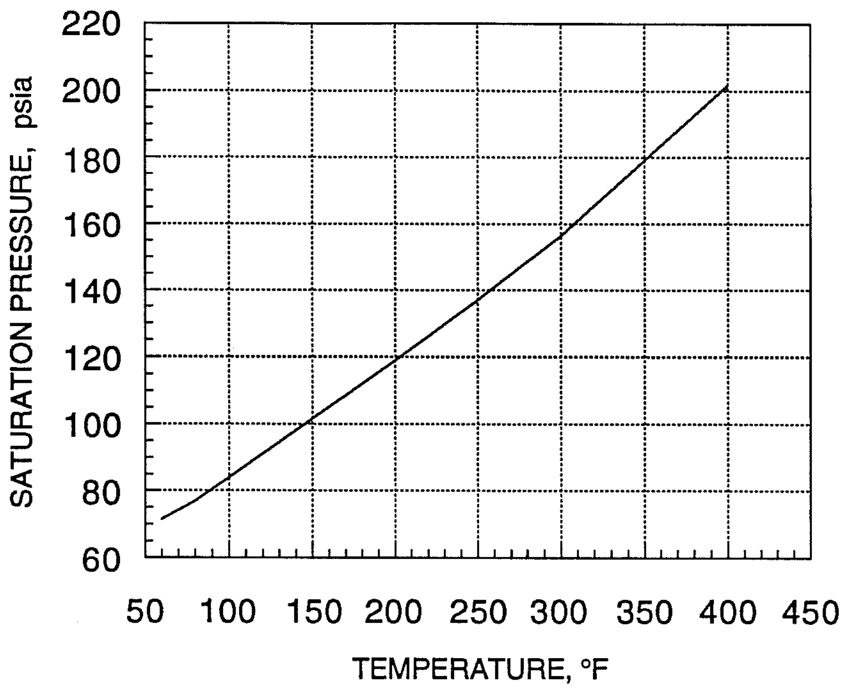

FIGURE 1. - Bubblepoint pressure for Shannon crude oil.

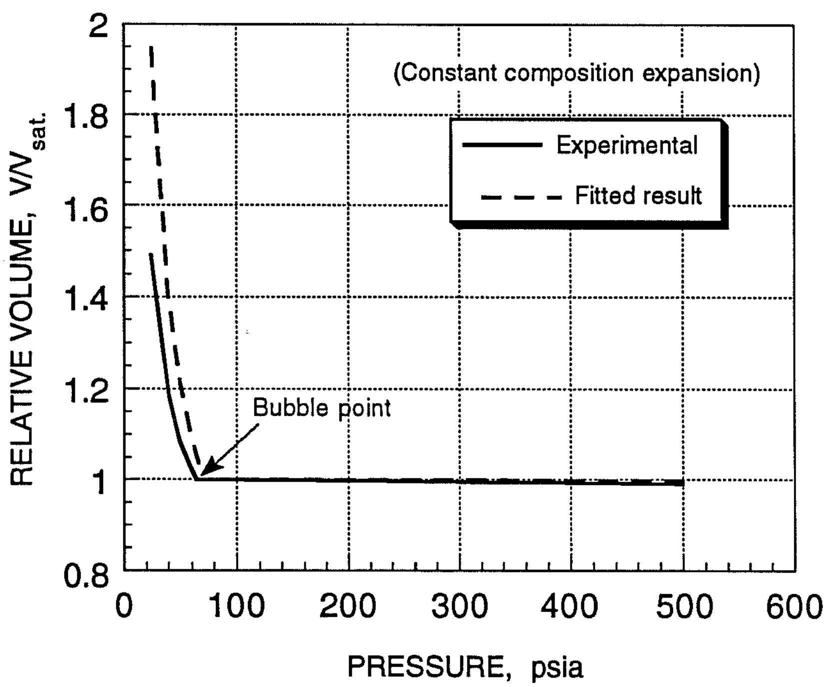

FIGURE 2. - Relative volume as a function of pressure.

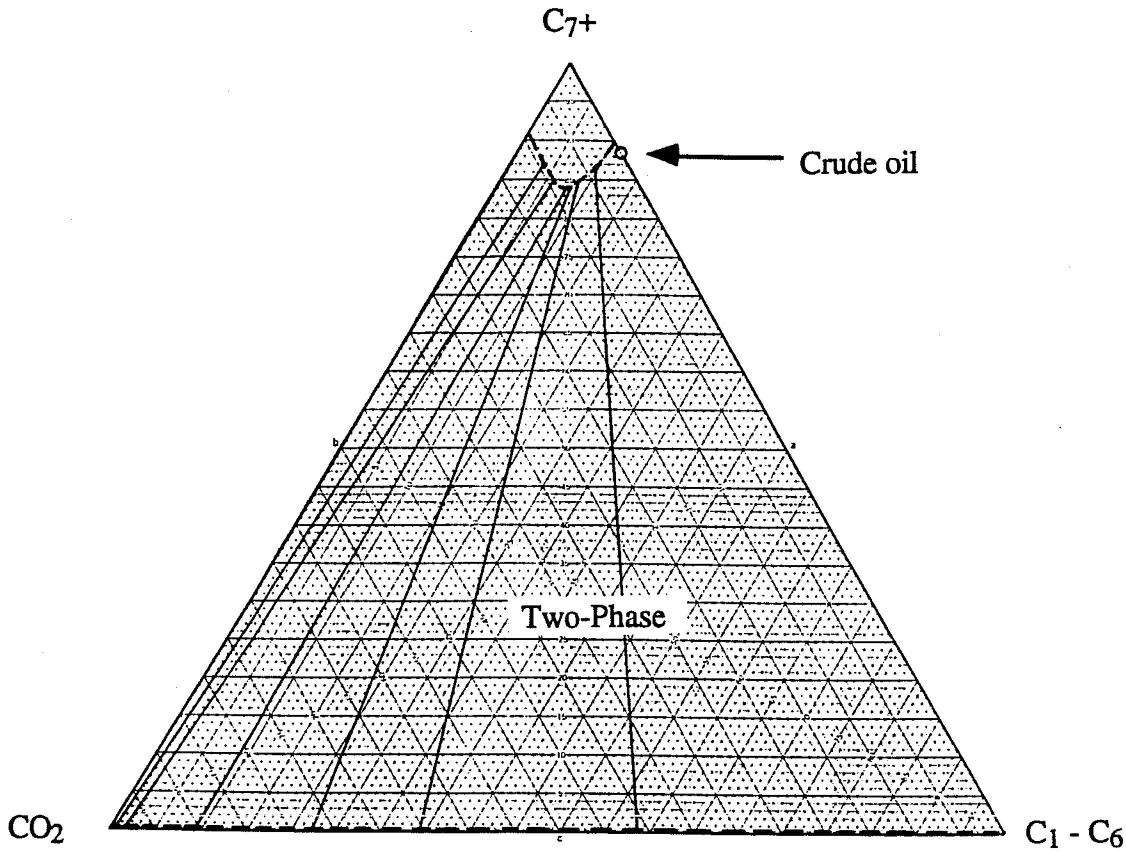

FIGURE 3. - Ternary phase diagram for Shannon crude oil with CO_2 (at 60° F, 65 psia).

The estimated MMP for CO_2 with Shannon crude oil is plotted as a function of temperature in Fig. 4 by using Glasp's Correlation.[2] It can be seen that the MMP is about 819 psia at 60° F. Under such pressure, carbon dioxide is already liquefied (the saturation pressure for CO_2 at 60° F is about 740 psia). Since the injected CO_2 gas will liquefy, it would be expensive to increase reservoir pressure from the present 65 psia to 819 psia by CO_2 injection. The solubility of CO_2 in crude oil is very low under present reservoir pressure. Therefore, at such low temperature and pressure conditions, CO_2 miscible or immiscible displacement is not feasible. Reservoir temperature and pressure of Shannon formation are the lowest among the NPR-3 reservoirs. Other formations such as Lakota and Tensleep may have high enough temperature and pressure for CO_2 flooding. Another consideration for the application of nitrogen gas or hydrocarbon gas injection is also impractical. Because the gas-oil ratio (GOR) is already low (19 scf/bbl), there is insufficient light hydrocarbon gas for reinjection. The MMP for N_2 and lean gas to achieve miscibility with such low GOR crude is much higher than that of CO_2. Therefore, hydrocarbon gas injection or nitrogen gas injection will not be beneficial.

In addition, geological information shows that NPR-3 reservoir is made up of fractured formations, and most oil production zones are shallow. These factors are unfavorable for gas EOR.

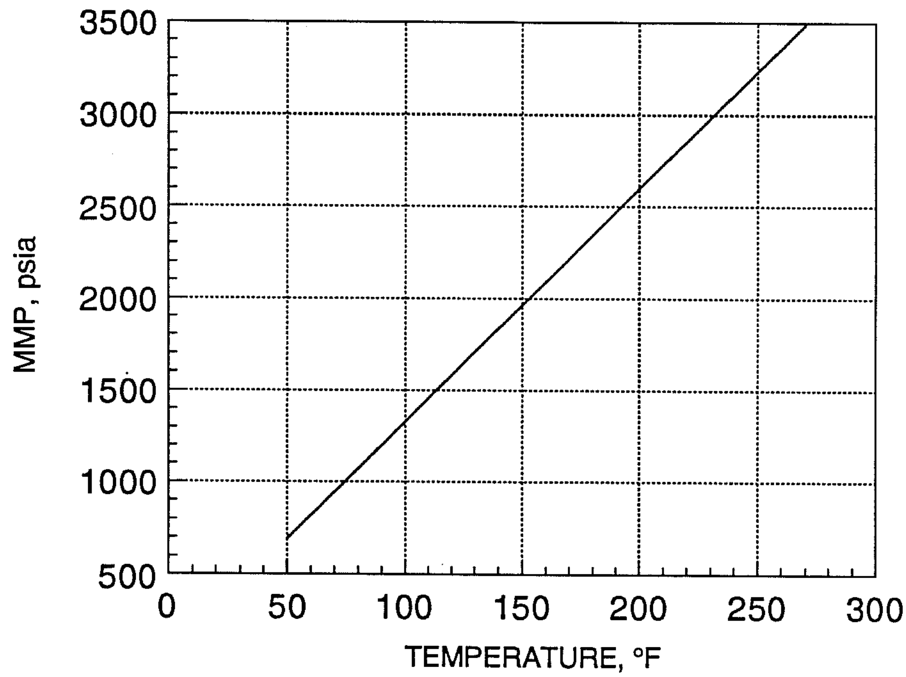

FIGURE 4. - Minimum miscibility pressure as a function of temperature for CO_2-Shannon crude oil.

CONCLUSIONS

Based on the preliminary study, gas EOR methods are not applicable in NPR-3 reservoirs, because the reservoir pressures and temperatures of the two major oil formations—Shannon and 2nd Wall Creek—are too low and the formations are fractured.

ACKNOWLEDGMENTS

This work was sponsored by the U.S. Department of Energy under cooperative agreement DE-FC22-83FE60149. We thank DOE for the use of the CMG phase behavior program.

REFERENCES

1. Moritis, G. CO_2 and HC Injection Lead EOR Production Increase. *Oil & Gas Journal,* April 23, 1990, pp. 49-81.

2. Glasp, P. *Generalized Minimum Miscibility Pressure Correlation.* SPE Paper No. 23893 - Unsolicited.

APPENDIX

RESERVOIR FLUID ANALYSIS

FOR

57-SX-3 WELL
51-41-SX-10-UPY WELL
NPR-3 FIELD
NATRONA COUNTY, WYOMING

SAMPLING INFORMATION

Well Record

Company	Lawrence-Allison & Assoc. West, Inc.
Well	57-SX-3
Field	NPR-3
Location	Natrona County, Wyoming

Field Characteristics

Formation Name	Shannon
Sand Name or Designation	Shannon
Date Completed	January, 1978
Original Reservoir Pressure (psig)	300 (estimated)

Well Characteristics

Original Produced Gas-Oil Ratio (scf/bbl)	--
Perforations (ft)	263-372
Elevations (ft)	5173
Total Depth (ft)	444
Last Reservoir Pressure (psig)	50 (estimated)
Reservoir Temperature (°F)	60
Information Provided By	Ralph Schulte

Sampling Conditions

Date Sampled	June 29, 1987
Flowing Tubing Pressure (psig)	100 (pumping)
Primary Separator Temperature (°F)	60
Primary Separator Pressure (psig)	1
Primary Separator Gas Rate (mscf/day)	.940
Primary Separator Oil Rate (bbl/day)	3.6
Second-Stage Separator Pressure (psig)	--
Second-Stage Separator Temperature (°F)	--
Second-Stage Gas Rate (mscf/day)	--
Second-Stage Oil Rate (bbl/day)	--
Stock Tank Oil Rate (bbl/day)	3.6
Separator Gas-Oil Ratio (scf/bbl)	260
Primary Separator Gas to Stock Tank Oil Ratio (scf/bbl)	260
Time Sample Taken	1:00 PM
Sample Taken By	Ralph Schulte

Standard cubic feet at 14.7 psia and 60°F
Oil rate for gas-oil ratio measured at 1st stage

Lawrence-Allison and Associates West, Inc.
57-SX-3 Well
NPR-3 Field
Natrona County, Wyoming

Analyst: Seiler
Laboratory: Houston
Date: 9-28-87

TABLE 1. HYDROCARBON ANALYSIS OF SEPARATOR PRODUCTS
AND CALCULATED WELLSTREAM

Component	Separator Oil Mole %	Separator Gas Mole %	Separator Gas GPM	Wellstream Mole %
Nitrogen	0.01	1.40		0.06
Carbon Dioxide	0.01	1.16		0.05
Hydrogen Sulfide	0.00	0.00		0.00
Methane	0.38	70.85		2.92
Ethane	0.05	6.58		0.29
Propane	0.17	8.82	2.426	0.48
i-Butane	0.14	2.17	0.709	0.21
n-Butane	0.40	4.33	1.364	0.54
i-Pentane	0.33	1.46	0.533	0.37
n-Pentane	0.42	1.28	0.462	0.45
Hexanes	6.37	1.14	0.468	6.18
Heptanes Plus	91.72	0.81	0.383	88.44
TOTAL	100.00	100.00	6.346	100.00

. Heptanes Plus Properties (Separator Oil)

API Gravity @ 60°F = 31.7
Specific Gravity @ 60/60°F = 0.8669
Molecular Weight = 231.9

. Separator Gas Properties

Calculated Gravity (Air = 1.0000) = 0.8875
Calculated Gross Heating Value = 1474.16 BTU/ft^3 of Dry Gas @ 14.7 psia and 60°F
Molecular Weight = 25.74

. Gas-Oil Production Ratios Used For Study

Primary Separator Gas/Separator Oil Ratio = 19.1 SCF/BBL @ 60°F
Primary Separator Oil/Stock Tank Oil Ratio = 1.0262 BBL/BBL @ 60°F
Primary Separator Gas/Stock Tank Oil Ratio = 19.6 SCF/BBL @ 60°F

. Stock Tank Oil Properties

API Gravity @ 60°F = 33.0
Specific Gravity @ 60/60°F = 0.8593

Lawrence-Allison and Associates West, Inc.
57-SX-3 Well
NPR-3 Field
Natrona County, Wyoming

Analyst: Douglas
Laboratory: Houston
Date: 9-1-87

TABLE 1a. EXTENDED ANALYSIS OF RECOMBINED WELLSTREAM

Component	Mole %	Temperature °F	Specific Gravity (60/60°F)	Molecular Weight
Nitrogen	0.06			
Carbon Dioxide	0.05			
Hydrogen Sulfide	0.00			
Methane	2.92			
Ethane	0.29			
Propane	0.48			
i-Butane	0.21			
n-Butane	0.54			
i-Pentane	0.37			
n-Pentane	0.45			
Hexanes	6.18			
Heptanes	11.25	183 - 234	0.7561	102
Octanes	13.21	234 - 280	0.8024	117
Nonanes	2.89	280 - 324	0.8208	132
Decanes	2.61	324 - 365	0.8280	147
Undecanes Plus	58.48	365+	0.8860	304
TOTAL	100.00			

Lawrence-Allison and Associates West, Inc.
57-SX-3 Well
NPR-3 Field
Natrona County, Wyoming

Analyst: Seiler
Laboratory: Houston
Date: 9-28-87

TABLE 2. CONSTANT COMPOSITION
PRESSURE-VOLUME MEASUREMENTS

Reservoir temperature = 65°F

Saturation pressure is 65 psia at 65°F

Thermal expansion of reservoir fluid from

$$65^{\circ}F - 300^{\circ}F = \left[\frac{\Delta V}{V \times \Delta T}\right]$$

@ 500 psia = 3.87×10^{-4} per °F
@ 400 psia = 4.04×10^{-4} per °F
@ 300 psia = 4.20×10^{-4} per °F

Compressibility of reservoir fluid at reservoir temperature:

$$\frac{1}{V_{avg}} \left[\frac{(V_1 - V_2)}{(P_2 - P_1)}\right]$$ from 500 psia to 300 psia = 19.40×10^{-6}

Specific volume at saturation pressure: ft^3/lb = 0.01901

Lawrence-Allison and Associates West, Inc.
57-SX-3 Well
NPR-3 Field
Natrona County, Wyoming

Analyst: Seiler
Laboratory: Houston
Date: 9-28-87

TABLE 3. PRESSURE-VOLUME RELATIONS OF RESERVOIR FLUID AT 65°F
(CONSTANT COMPOSITION EXPANSION)

Pressure (psia)	Relative Volume (V/V_{sat})*	Liquid Phase Density (gm/cm^3)	Y-Function $\frac{P_{sat} - P}{P(V/V_{sat} - 1)}$
500	0.9916	0.8503	
400	0.9935	0.8487	
300	0.9954	0.8471	
100	0.9993	0.8438	
65++	1.0000	0.8432	
60	1.0234		3.563
50	1.0862		3.480
40	1.1839		3.398
25	1.4887		3.274

*Volume at pressure divided by volume at saturation pressure

++Bubble Point Pressure

Lawrence-Allison and Associates West, Inc.
57-SX-3 Well
NPR-3 Field
Natrona County, Wyoming

Analyst: Seiler
Laboratory: Houston
Date: 9-28-87

TABLE 4. PRESSURE-VOLUME RELATIONS OF RESERVOIR FLUID AT 300°F
(CONSTANT COMPOSITION EXPANSION)

Pressure (psia)	Relative Volume (V/V_{sat})*	Liquid Phase Density (gm/cm^3)	Y-Function $\frac{P_{sat} - P}{P(V/V_{sat} - 1)}$
500	0.9846	0.7794	
400	0.9900	0.7751	
300	0.9954	0.7709	
215++	1.0000	0.7674	
200	1.0493		1.521
190	1.0901		1.460
180	1.1390		1.399
100	1.2623		0.911

*Volume at pressure divided by volume at saturation pressure

++Bubble Point Pressure